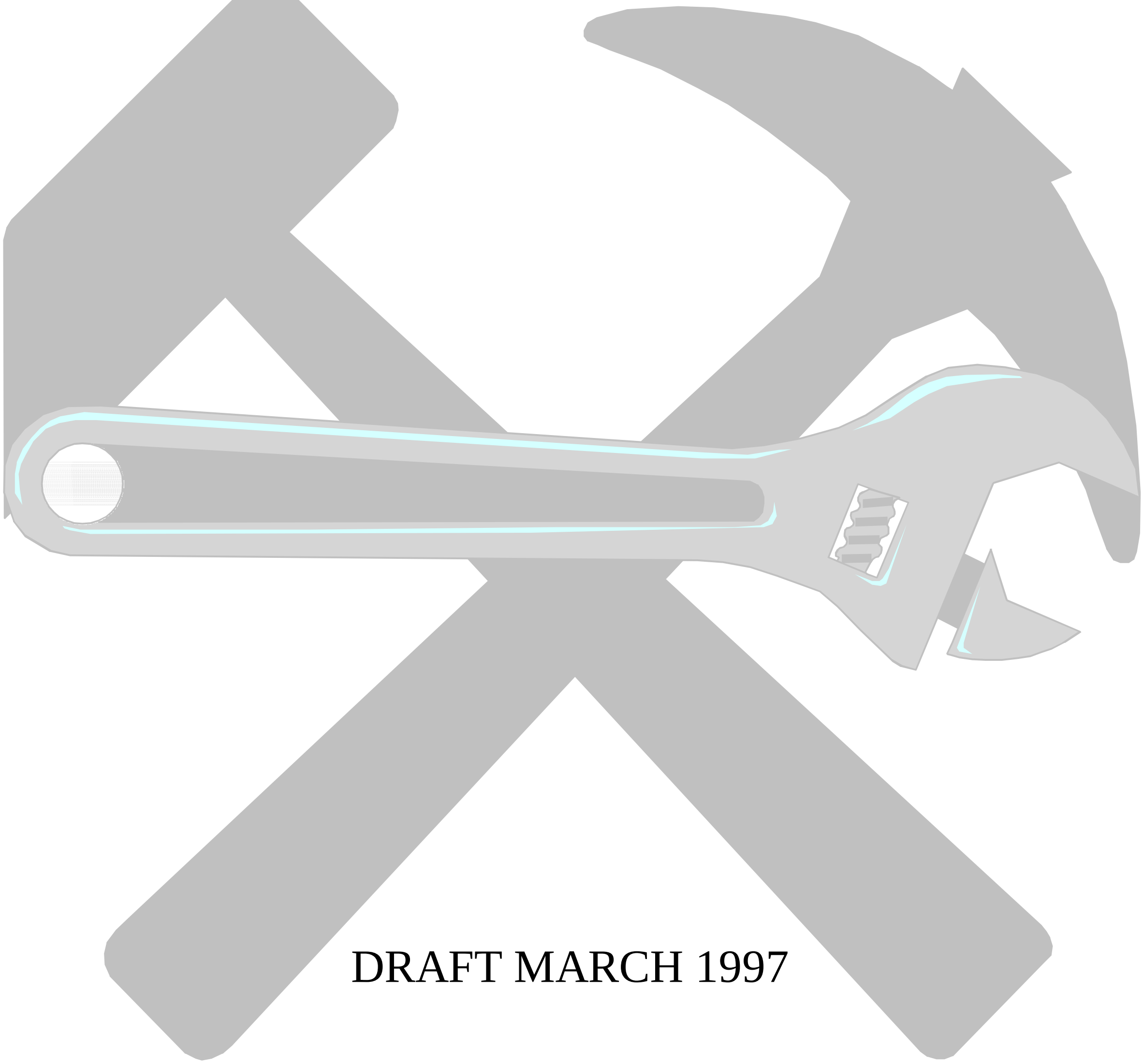
PRACTICAL WAYS TO REDUCE EXPOSURE TO DIESEL EXHAUST IN MINING -- A TOOLBOX



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Mine Safety and Health Administration

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Acknowledgments

The Mine Safety and Health Administration (MSHA) held a series of workshops in the fall of 1995 to obtain input from the mining community on ways of reducing miners' exposure to diesel particulate matter from the exhaust of diesel engines.

MSHA thanks those who attended the workshops and willingly shared their ideas on practical ways to reduce exposure to diesel emissions in mining. These practical ideas have been utilized in producing this "Toolbox." A key objective of the toolbox is to facilitate the exchange of practical information on ways to reduce miner exposure to diesel exhaust emissions.

Thanks are also extended to former U.S. Bureau of Mines scientists, from whose diesel-related publications the text of this handbook draws, and to Robert Waytulonis, Associate Director of the University of Minnesota's Center for Diesel Research.

Credit is also given to the following MSHA staff for their efforts in organizing the Diesel Exhaust Workshops, their role in selecting pertinent quotations from the workshop transcripts, and in contributing to or reviewing this manual: Kathy Alejandro, Janet Bertinuson, Teresa Carruthers, Jerry Collier, James Custer, George Dvorznak, Guy Fain, Ron Ford, Keith Gaskill, Don Gibson, Hal Glassman, Robert Haney, Jerry Lemon, Pamela King, James Kirk, Jon Kogut, Cheryl McGill, William McKinney, Ed Miller, Charlotte Richardson, Bryan Sargeant, George Saseen, Erick Sherer, Thomas Tomb, Pete Turcic, and Sandra Wesdock. Thanks also to Liz Fitch and Mike Doyle for their help in reviewing early drafts, to Todd Taubert for help with the section on lugging, to Reggie McBee for editorial support, to Ann Masters for graphic artist support, and to Bill West for internet conversions.

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Andrea Hricko of MSHA provided guidance in organizing the Diesel Workshops and worked closely with Winthrop Watts and Thomas Tomb in creating this "Toolbox." Thanks to Peter Galvin for consolidating the final draft.

Special thanks to Winthrop F. Watts, Jr., Ph.D.,
of the University of Minnesota, Center for Diesel Research,
for conceptualizing the "Toolbox"
and for writing the first drafts of this manual under contract to the
Mine Safety and Health Administration

HOW TO USE THIS PUBLICATION

Who should use this publication?

If your mine uses diesel-powered equipment, or is contemplating its use, you will find this toolbox a useful guide. So too will those who help mine operators select or maintain mining equipment. The toolbox can be read cover-to-cover as a basic reference, or used as a troubleshooting guide by diesel equipment operators and mechanics. Some knowledge of engines is assumed, although a glossary is provided.

Is this only of interest to underground mines?

No. While some sections are of special interest only to underground mines (e.g., ventilation), most of this publication will be of value to surface mines as well.

Is the toolbox useful in any type of mining?

Yes. The ideas and concepts are just as relevant in metal and nonmetal mines as they are in coal mines, and many of the controls described are available to operators in both sectors.

How can I find what I need quickly?

The Table of Contents on the first page of this handbook can be used to quickly locate a topic of interest. A complete Index is included at the very end of this handbook. Technical terms or materials are discussed or referenced in appendices.

If I follow the recommendations in the toolbox, will I be in compliance with MSHA requirements?

This publication is NOT a guide to applicable Federal or State regulations on the use of diesel engines, or the measurement or control of their emissions, on mining property. Selection of a toolbox approach must be made in light of the need to comply with such requirements. Appendix D references some of the requirements which should be consulted -- and see the note on the next page about the new underground coal rules. Please contact MSHA if you have any questions about applicable requirements.

There is currently no rule to clearly define for each mine how far it needs to go in limiting miner exposure to the particulate component of diesel exhaust. MSHA is developing such a rule which it expects to publish as a proposed rule by July 1997. There will be opportunity for comment, hearings, and further work before a final standard is issued. But there is no reason why the mining community has to wait for a regulation to start solving this problem, and the Toolbox should be a significant aid in that regard.

Does MSHA want my input on this subject?

MSHA welcomes your comments on how to improve future editions of this toolbox, and information on your experiences in reducing exposure to diesel emissions. Please direct any comments to : Chief, Pittsburgh Safety and Health Technology Center, Cochrans Mill Road, P.O. Box 18233, Pittsburgh, Pa. 15236. You may also fax them to 412-892-6928, or e-mail them to chiefpshtc@msha.gov.

> SPECIAL NOTE: THE USE OF DIESEL-POWERED EQUIPMENT IN UNDERGROUND COAL MINES
>
> On April 25, 1997, certain key provisions of MSHA's final rule on the use of diesel-powered equipment in underground coal mines will go into effect. Other provisions of that rule will go into effect over the next three years. Some of these regulations require the implementation of particular strategies recommended in this toolbox.
>
> Since the mining community is still becoming familiar with these requirements, some of them are noted in the text at appropriate places, using SMALL CAPS or a box. MSHA hopes this will serve as a useful reminder for this sector, without being distracting to the remainder of the mining community.
>
> A compliance guide for the new underground coal mine diesel regulations, in the form of Questions and Answers, is currently being prepared by MSHA, and will be widely circulated when it has been completed. While this toolbox is not a substitute for the compliance guide or a copy of the regulations, neither are the compliance guide or the regulations a substitute for this toolbox -- all three documents will be useful for underground coal operators and miners.

INTRODUCTION

The Problem

Diesel engines are widely used in mining operations because of their high power output and the increased mobility they allow. Many mine operators prefer diesel-powered machines because they are more powerful than most battery-powered equipment and can be used without electrical trailing cables which can restrict equipment mobility. Underground coal, metal and nonmetal mines currently use approximately 10,000 diesel machines and about 35 percent of these are used for heavy-duty mining production applications. The use of diesel equipment in mining is on the rise, as described by speakers at a series of Workshops on Controlling Diesel Emissions sponsored by MSHA in the fall of 1995:

> “In 1985, we had a total mine horsepower of 6,851 horsepower. Today, in 1995, our horsepower has risen to 14,885 horsepower in the mine” - David Music, Akzo Nobel Salt’s Cleveland Mine.
>
> “... Today we have over a hundred pieces of diesel equipment, large and small, anywhere from that Bobcat to large section scoops, generators, welders, compressors, trucks that are used on open highways, and diesel trucks.”- Forrest Addison, Utah Coal Miner (UMWA)

The estimated distribution of diesel equipment in mining is shown in Table 1. An estimated 30,000 miners work at underground mines using such equipment and an estimated 200,000 miners work at surface operations using such equipment.

Table 1. Estimated Distribution of Diesel Equipment in Mining

	Mines Using Diesel Engines			
	Underground Mines		Surface Mines	
Mine type	# Mines	# Engines	# Mines	# Engines
Coal	180	2,900	2,000	21,000
Metal and nonmetal	300	7,200	11,000	115,000
Totals	480	10,100	13,000	136,500

There is a downside, however, to the use of diesel equipment, especially in the environment of underground mines. The problem is the potential acute and long-term health effects of exposure to various constituents of diesel exhaust, which consists of noxious gases and very small particles.

The gases in the diesel emissions include carbon monoxide, carbon dioxide, nitric oxide, nitrogen dioxide, sulfur dioxide, aromatic hydrocarbons, aldehydes and others. MSHA sets limits on miner exposure to a number of these gases.

The particles in the diesel emissions are known as "diesel particulate" (DP), or "diesel particulate matter" (DPM). Diesel particulate matter from the exhaust consists of tiny particles, which are small enough to be inhaled and retained in the lungs. The particles have hundreds of chemicals from the exhaust adsorbed (attached) onto their surfaces.

The mining community is very familiar with the specific hazards long associated with other particulates of respirable dimensions -- like coal mine dust and dust containing silica. A recent body of evidence, based on studies of air pollution, suggests that exposure to smaller particles (including those present in diesel exhaust) is likewise associated with increased rates of death and disease. Specific evidence has also been accumulating that exposure to high levels of DPM can increase the risk of cancer. In 1988, the National Institute for Occupational Safety and Health recommended that whole diesel exhaust be regarded as a "potential occupational carcinogen," and that reductions in workplace exposure be implemented to reduce cancer risks. In 1989, the International Agency for Research on Cancer declared that "diesel engine exhaust is probably carcinogenic to humans." In 1995, the American Conference of Governmental Industrial Hygienists (ACGIH) added DPM to its "Notice of Intended Changes" for 1995-96, recommending a threshold limit value (TLV®) for a conventional 8-hour work day of 150 micrograms per cubic meter (150 $\mu g/m^3$).

NOTE ON DIESEL PARTICULATE MATTER MEASUREMENTS: MICROGRAM v. MILLIGRAM

In this Toolbox, we have chosen to express measurements of DPM in micrograms (μg) per cubic meter of air. A microgram is one millionth of a gram. However, in many references, you may see the DPM measurements expressed as milligrams (mg) per cubic meter of air. A milligram is one thousandth of a gram.

$1\ mg/m^3$ = 1 milligram per cubic meter of air

$1\ \mu g/m^3$ = 1 microgram per cubic meter of air

1 milligram = 1000 micrograms. So if you want to convert from milligrams to micrograms, multiply by 1000 -- or move the decimal point three places to the right.

For example, $0.15\ mg/m^3 = 150\ \mu g/m^3$.

Many non-mining workplaces where diesel equipment is used have levels of DPM well below the recommended ACGIH TLV®. In contrast, studies conducted by various scientific researchers demonstrate that exposures to DPM in mining environments can be significantly higher than exposures in the ambient air or in other workplaces.

Figure 1 provides a visual comparison of the DPM exposures of miners with the exposures of other groups of workers who routinely work with diesel-powered equipment. The chart also shows the exposure of the general public (ambient air), and the proposed ACGIH TLV®. As can be readily seen, exposures in mining environments are significantly higher.

Figure 1

MEASURED OCCUPATIONAL EXPOSURES, µg/m^3

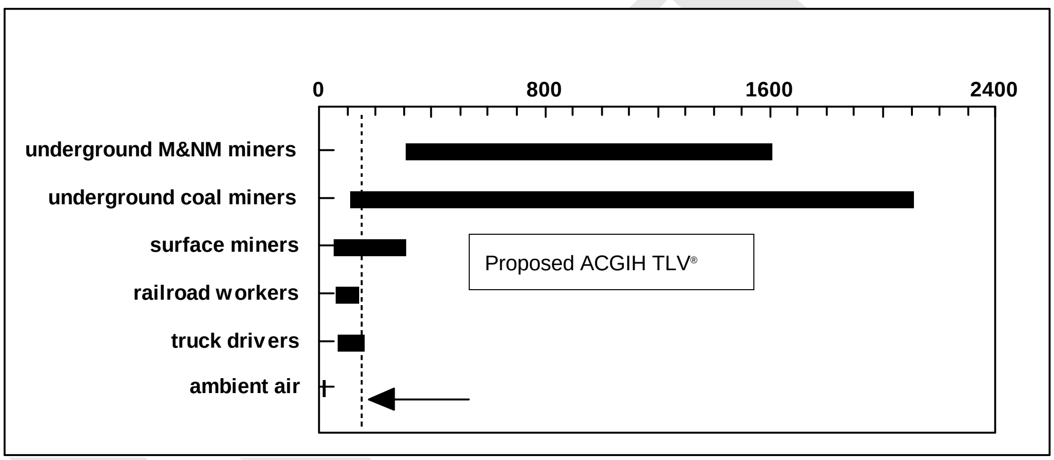

Table 2 provides additional detail about the levels of exposure in U.S. mines. The higher concentrations in underground mines are typically found in the haulage ways and face areas where numerous pieces of equipment are operating, or where insufficient air is available to ventilate the operation. In surface mines, the higher concentrations are typically associated with truck drivers and front-end loader operators.

Table 2. Estimated Full-Shift Diesel Particulate Matter Exposure in U.S. Mines

Mine type	Range of exposure, µg/m^3	Mean exposure, µg/m^3
Surface	< 100-300	< 200
Underground coal	100-2100	900
Underground metal and nonmetal	300-1600	700

In 1988, MSHA's Advisory Committee on Diesel-Powered Equipment in Underground Coal Mines recognized a number of risks related to the use of diesel-powered equipment in such mines, including the potential risks of exposing miners to diesel emissions. The Committee made recommendations to address its concerns.

Since that time, MSHA has taken several actions relevant to diesel exhaust. In 1989, MSHA proposed "air quality" regulations which would, among other things, set stricter limits on some diesel exhaust gases. These regulations remain under review. In 1996, after notice and comment, MSHA issued final regulations for the use of diesel-powered equipment in underground coal mines. These rules will begin to go into effect over a 3-year period. And in response to a specific recommendation of the Advisory Committee that "the Secretary of Labor should set in motion a mechanism whereby a diesel particulate standard can be set....", MSHA is developing a proposed rule toward that end.

There are some cases where alternative power sources (e.g., electricity or batteries) may be the solution. But when diesel engines are used, the mining community needs to understand the potential health risks they present and take steps to reduce the hazards.

> "...We're very dependent on diesel engines. At the same time, air quality in the mine is very important to IMC. We realized a long time ago that it affects both miner health and morale, and for us morale and productivity go hand in hand. So beginning in the 1970s we consciously undertook a program of improving our air quality...." - Scott Vail, Ph.D., IMC Global Carlsbad Mine
>
> "...Of all the health issues that we're dealing with in the mining industry, this issue is at the top of the list...As I travel across this country, I hear more about exposure to diesel exhaust than any other single issue in the mining industry." - Joe Main, United Mine Workers of America

Addressing the Problem: The Experience of the Mining Community

In 1995, MSHA established an internal working group to explore measures to reduce miners' exposure to DPM. This group organized a series of workshops to solicit input from the mining community. The workshops were designed to discuss the potential health risks to miners from exposure to DPM, ways to measure and limit DPM in mine environments, and regulatory or other approaches to ensure a healthful work environment. These workshops provided a useful forum to exchange views and concerns about limiting diesel exhaust exposure. More than 500 members of the mining community attended these workshops, providing evidence that reducing miners' exposure to diesel exhaust emissions, especially in underground mines, is a high priority for the mining industry.

The experience of the mining community appears to support several conclusions --

- The levels of exposure to DPM in mines depends upon engine exhaust emissions, the use of exhaust after treatment and its efficiency and, particularly in underground mines, ventilation rate and system design.

- Engine emissions are governed by engine design, work practices, duty cycle, fuel quality and maintenance. Reducing engine emissions will decrease the amount of DPM that needs to be controlled by other means and will reduce the exposure of miners.

- There is no single emission control strategy that is a panacea for all problems.

- Monitoring is necessary to evaluate a DPM control program.

A major objective of this publication is to facilitate the exchange of practical information within the mining community on ways to reduce miners' exposure to diesel exhaust emissions. The handbook focuses on currently available methods of control as opposed to methods in the research and development stages. Each of the various technologies presented in the handbook will assist in reducing or monitoring worker exposure.

Where possible, the handbook quotes specific examples of methods tested or used by the mining industry to reduce exposure to diesel emissions. These quotations are taken directly from public transcripts of the 1995 MSHA workshops, and were selected to provide a representative sample of views expressed..[1] All quotations are offset from the main text by boxes. The handbook also draws extensively from diesel-related publications prepared by former U.S. Bureau of Mines scientists. Please note that key words and phrases are highlighted in bold italicized type for easy reference. { } brackets are used to insert explanations not found in the original quotation, "..." are used to indicate that words were removed to make the quote shorter.

MSHA hopes that the mining community will benefit from the exchange of this practical information and will take steps to reduce miners' exposure to diesel emissions, utilizing the variety of techniques described in this publication and other methods as they are developed. The Agency encourages an ongoing exchange of information on strategies to further reduce exposure to diesel emissions and to protect the health of miners.

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[1] **The quotations cited in this publication do not necessarily represent the views and/or policies of MSHA, nor of the organizations or companies at which the speakers work (or worked). MSHA recognizes that some affiliations have changed since the workshops. Names and affiliations at the time of the workshop are used. Finally, reference to specific manufacturers and/or products does not imply endorsement by MSHA or the U.S. Government.**

The Reason for a "Toolbox" Approach

This publication introduces a ?toolbox” approach to reducing miners’ exposure to diesel exhaust emissions. A toolbox offers a choice of tools, each with a specific purpose. One tool after another may be used to find a solution to a problem or several tools may be tried at the same time.

Reducing exposure to diesel emissions lends itself to a ?toolbox? approach because no single method or approach to reducing exposure may be suitable for every situation. Examples of the “toolbox” approach to reducing exposure to diesel emissions in a mine were described at the 1995 MSHA workshops:

> “Since the mid-1980s Homestake has initiated a number of work steps and tests to control the diesel emission components, and these are engine alternatives, maintenance, exhaust aftertreatments, fuels, dilution ventilation and engine type.”... “To summarize our experiences with diesel particulate matter, we've had good luck with respirators, maintenance and fuels. We've had mixed results with diesel particulate filters and with airflows. And results are still pending on engine type. We are going to continue working in all of these areas.” - John Marks, Homestake Mining Company
>
> “ At Galatia a three-point approach is used to ensure safe and healthy diesel operating conditions. First, the mine is designed to provide vast volumes of air to all the active workings... Second, a well-conceived maintenance program strives to maintain optimum engine performance and thereby control diesel exhaust emissions. The maintenance program consists of regularly scheduled replacements of fluids and filters, operating performance evaluations and additional weekly permissibility inspections, a regularly scheduled emissions test... and... a training program to educate maintenance personnel in the engine operating recommendations and requirements. The third point in our approach is the use of control technology.... All permissible vehicles ... at Galatia use a wet scrubber for initial particulate reduction. Additionally, 10 Ramcars that are normally assigned to production units have been retrofitted with the pleated paper diesel particulate filter. Additional vehicles are being retrofitted during equipment rebuilds.” - Keith Roberts, Kerr-McGee, Galatia Mine
>
> “...Ventilation is an important control....” “...Through clean-burning diesel engines, low sulfur fuels, and effective aftertreatment technology, we can reduce emissions at the engine." - Jeff Duncan, United Mine Workers of America.

The toolbox is divided into nine sections --

* use of low emission engines
* use of low sulfur fuel, fuel additives and alternative fuels
* use of after treatment devices
* use of ventilation
* use of enclosed cabs
* diesel engine maintenance
* work practices and training
* fleet management
* respiratory protective equipment.

Each section covers specific methods that are being used to reduce emissions or exposure. Use of these methods will be determined by the specific circumstances found at each mine.

> "There is no single control that is a panacea for all the emission problems. Due to differences in the mine design and the mine geology, the equipment types and sizes, and their duty cycles, ... different types of controls are used." - Robert Waytulonis, Center for Diesel Research, University of Minnesota
>
> "Because of the interrelationship of the various control technologies on workers' exposures, mine operators often choose the combination of controls that is best suited to their operations. In some cases, because of the number and size of equipment, ventilation alone may be sufficient to control worker exposures. In other cases it may be necessary to reduce engine emissions or utilize after treatment devices." - Robert Haney, Mine Safety and Health Administration

TOOLBOX

Use of Low Emission Engines

Low emission engines are produced by engine manufacturers to meet increasingly stringent Environmental Protection Agency (EPA) regulations. Mine operators can benefit from discussing the condition of their diesel fleet with diesel manufacturers prior to ordering new diesel engines.

Low-emission engines typically operate at high fuel injection pressures which provide a more efficient and complete combustion of fuel. These engines are frequently turbocharged to optimize power, performance, and emissions. After cooling (cooling intake air that is compressed and heated by the turbocharger prior to induction into the combustion chamber) is used to reduce oxides of nitrogen (NO_x). Electronic engine control is another technological improvement, which optimizes the fuel-to-air ratio resulting in lower emissions.

As a result of EPA regulations in 1988, "on-highway" heavy duty diesel engine emissions have been significantly reduced. Emissions standards have driven particulate emissions levels for such engines from 0.6 gm/hp-hr in 1988 to less than 0.1 gm/hp-hr in 1994, and oxides of nitrogen emissions from 10.7 gm/hp-hr in 1985 to 5.0 gm/hp-hr in 1991. The EPA regulations provide a schedule for continued improvement, and a second generation of improvements is on the drawing boards.

In 1996, the EPA established emission regulations for almost all land based nonroad ("off-highway") diesels, such as construction equipment. These regulations specify emission levels that nonroad engines must meet depending on the horsepower of the engine. In 1996, the regulations affect only nonroad engines between 175-750 horsepower. For this category, the 1996 standard reduces particulate emissions from as high as 1.0 gm/hp-hr to 0.4 gm/hp-hr and oxides of nitrogen emissions to below 6.9 gm/hp-hr. The rule phases in limits for other horsepower engines. Modern engines developed for nonroad use are expected to provide the mining industry with a greater choice of low emission engines for use underground. It should be noted that diesel engines used in underground coal mines are primarily indirect injection engines (pre-chamber), which in some cases could meet certain EPA nonroad requirements.

Benefits can be gained by replacing older model engines that require more maintenance with newer engines. Lower emissions and greater machine availability to perform the work (i.e., the machine does not break down as often) are normally achieved with a newer type engine. Engines that have been approved or certified by agencies like MSHA, EPA or the state of California generally have lower emissions. Larger on-highway type engines that have been built after 1988 and non-road engines built after 1996 have been designed to produce lower emissions to meet the stringent on-highway emission standards discussed above. For engines approved under Part 7, subpart E for underground mining applications, MSHA determines a particulate index (PI). The PI indicates the quantity of ventilation air required to dilute particulate emissions from a specific engine operated over a test cycle to a concentration of 1 milligram (i.e., 1000 micrograms) per cubic meter of air. Mine operators and machine manufacturers of mining equipment can use the PI in selecting and purchasing engines. The lower the PI number, the lower the particulate emissions for the same horsepower engine. Mine operators may also use the PI to roughly estimate each engine's contribution to the mine's levels of total respirable dust in coal mines or the levels of diesel particulate in metal/nonmetal mines. In underground coal mines, all engines must be MSHA-approved engines by November 25, 1999.

> "... Diesel engines continue to become cleaner; there will be more emission legislation out there in the future.... Diesel engine fuel efficiency has improved at the same time; power density has continued to climb; diesel engine life has steadily increased." - Peter Woon, Cummins Engine
>
> "... There has been about a 90 percent reduction in just going to cleaner engine technologies, and these are results that apply to well-maintained, new engines..." - David Hofeldt, Ph.D., University of Minnesota
>
> "Now, this class of engines {modern, low emission engines} has high horsepower, typically from 250 hp up to 500 hp, so they are not suitable for all types of mining equipment." ... "They have the advantage of producing 80-90 percent less particulate than the conventional naturally-aspirated prechamber engines. They consume on the order of 25 percent less fuel. And in the case of the Cat 3306 swirl, it's a drop-in replacement for some of the older 3306 technology." - Robert Waytulonis, Center for Diesel Research, University of Minnesota
>
> "We felt that the problems we had with filters ... caused so many problems that it was a lot better to clean up the source, and so we got cleaner engines. We are using one manufacturer's engine. We're getting another -- in fact, we're getting one of the new ... Detroit Diesel engines with electronic controls just for that reason in the next machine we buy.... Utilization of highway-type diesel engines in our replacement engine program is providing us cleaner burning, reliable engines at a lower cost than the regular mining-type engines and a post-combustion device..." - Ray Ellington, Morton Salt
>
> "{Start} with buying a clean engine as opposed to some of these polluting engines that dump out all kinds of NO_x and carbon monoxide. Buy the cleaner engines..." - Joe Main, United Mine Workers of America.

Use of Low Sulfur Fuel, Fuel Additives and Alternative Fuels

The quality of the ***diesel fuel*** influences emissions. Sulfur content, cetane number, aromatic content, density, viscosity, and volatility are interrelated fuel properties which can influence emissions. Sulfur content can have a significant effect on diesel particle emissions. In addition, it affects sulfur oxide (SO_x) emissions, all forms of which are toxic and limited in mine atmospheres. Moreover, SO_x emissions can poison catalytic converters, and the continued use of high sulfur fuel will contribute to increased piston ring and/or cylinder liner wear. Cetane number affects all regulated pollutants, and fuel aromatic content affects DPM and nitrogen oxides (NO_x). Therefore, it is important to provide fuel distributors with specific fuel specifications and recommended property limits when purchasing diesel fuel. Table 3 lists recommended property limits for diesel fuel.

Table 3. Recommended Property Limits for Diesel Fuel

Property	Limit
Cetane number	> 48
Aromatic content	< 20 percent
90 percent distillation temperature	< 600º F
Sulfur content	< 0.05 percent by mass

Use of ***low sulfur diesel fuel*** (< 0.05 percent sulfur) reduces the sulfate fraction of DPM emissions, reduces objectionable odors associated with diesel use and allows oxidation catalysts to perform properly. A further benefit in the use of low sulfur fuel is reduced engine wear and maintenance costs. Fuel sulfur content is a particularly important parameter when the fuel is used in low emission diesel engines. Low sulfur diesel fuel is available nationwide due to EPA regulations. As of April 25, 1997, diesel-powered equipment in underground coal mines must use low-sulfur fuel.

"... There is an ASTM-975-93 specification {on low sulfur fuel} from the EPA. All you have to do is to specify that fuel on your purchase order, and this is the fuel they have to deliver. You just have to insist on it." - Norbert Paas, Paas Technology

"... Homestake used a straight No. 2 diesel fuel with up to 0.5 percent fuel sulfur until 1991 when we switched to a premier No. 2 with 0.12 percent fuel sulfur. Since about the start of 1995 we've gone to the 0.05 percent No. 2." - John Marks, Homestake Mining Company

> "For fuel we use a low sulfur diesel fuel that typically averages 0.041 percent sulfur and a cetane number of 54." - Bill Olsen, Mountain Coal Company, West Elk Mine

Increased cetane number and volatility, as measured by a fuel's distillation temperature characteristics, reduces hydrocarbon emissions and reduces the tendency to produce white smoke, which is produced when the engine is cold or under low load. White smoke consists primarily of water vapor, unburned fuel and a small portion of lube oil. Fuel with a cetane number greater than 48 and a seasonably adjusted cloud point reduces cold-start hydrocarbon emissions, odor, noise, irritant and fuel system wax separation problems. The cetane number of typical U.S. diesel fuel ranges between 40 and 57.

> "... Cetane number is very important - needed for good starting, good combustion and for emission performance of engine .... When cetane number is improved, either by cetane additive or base fuel composition ... so that cetane number is improved from 45 to 55, there's a dramatic reduction in hydrocarbons ... and ... in carbon monoxide... and more than 10 percent reduction in particulates" - Kashmir Virk, Texaco, Inc.

Reducing the aromatic hydrocarbon content and the 90 percent distillation temperature of the fuel reduces the soluble organic fraction of DPM and NO_x emissions. Typical No. 2 diesel fuel in the U.S. has an aromatic hydrocarbon content of 20 to 40 percent.

A variety of ***fuel additives*** are being sold to reduce emissions. Cetane improvers increase the cetane number of the fuel, which may reduce emissions and improve starting. Detergents are used primarily to keep the fuel injectors clean. Dispersants or surfactants prevent the formation of thicker compounds that can form deposits on the fuel injectors or plug filters. Lubricity additives are similar to corrosion inhibitors and are frequently added to fuel by petroleum producers. There are also stability additives, which prevent the fuel from breaking down when it is stored for long periods of time. Only additives registered by the EPA are recommended for use, to ensure that no harmful agents are introduced into the mine environment. As of April 25, 1997, only diesel fuel additives that have been registered by EPA may be used in diesel-powered equipment in underground coal mines.

> "... There's a variety of different types of compounds you can add that contain oxygen. Typical diesel fuel doesn't have much oxygen ...". {When significant quantities of oxygenates are added to fuel, the oxygen content of the fuel is increased}, "...You end up seeing ... reductions in particulate emissions, hydrocarbon emissions and CO...." - David Hofeldt, Ph.D., University of Minnesota

> "... Detergent-type additives in the fuel primarily prevent cracking effects or hollowing effects of the injectors. And if you don't use a detergent additive, pretty much all your emissions go up over time... {However} just using a detergent is not going to make up for an engine that's wearing out." ... "Metals as a group reduce the visible smoke output." ... The problem with metal additives is they show up on the particulate. Metals don't burn up." ... "Metals are known to have some biological effects just like diesel particulates would. So I would not recommend that you {use} any of the metal additives for reducing {diesel particulates}." - David Hofeldt, Ph.D., University of Minnesota.
>
> "We took a very serious look at metal additives ... for on-highway trucks .... We -- Caterpillar -- and the industry decided not to go that way ...{One} concern was {that} these chemicals may actually cause health effects in their own rights..." - John Amdall, Caterpillar

Another promising control technology is ***alternative fuel***, especially biodiesel fuels made from methyl esters derived from soybeans although these are not readily available on the market. This type of fuel contains about 10 percent oxygen, has a high cetane number, and a much higher flash point. These properties improve combustion, starting, performance and safety characteristics of the fuel. To maximize the reductions in exhaust emissions, it is recommended that biodiesel fuels be used with a diesel oxidation catalyst. EPA has certified a biodiesel brand known as Envirodiesel® , which is used with a diesel oxidation catalyst, for use by urban bus transit operators in complying with Clean Air Act requirements.

> "The Bureau of Mines demonstrated that the combination of methyl soyate fuel and modern diesel exhaust catalyst is a passive control scheme that is very effective.... {In tests conducted at the Homestake Gold Mine}, a Wagner load-haul-dump was operated using a 100 percent methyl soyate fuel and a modern catalyst. Compared to baseline emissions, a 70 percent reduction in the ambient levels of {diesel} particulate matter was achieved...." - Robert Waytulonis, Center for Diesel Research, University of Minnesota
>
> "...Homestake cooperated with the Bureau of Mines to successfully evaluate a soymethylester {biodiesel} fuel...miner acceptance was good, and the leftover {biodiesel} fuel was quickly used by our miners." - John Marks, Homestake Mine

Use of Aftertreatment Devices

Water scrubbers are a safety device used on "permissible" equipment in underground mines. Water scrubbers perform three functions: cooling exhaust gases to safe temperatures, arresting sparks and arresting flames. The exhaust airflow from a diesel engine passes through water, making direct contact with the water. This direct contact with the water cools the air and quenches flames and sparks. Although not intended as an emission control device, scrubbers have been shown to remove about 30% of DPM from an engine's exhaust stream. Water scrubbers have no significant effect on gaseous emissions.

> "The water scrubber ... is not an emission control, it's a safety control, but incidentally, it will remove 20 to 30 percent of the particulate ...." "They require frequent maintenance." - Robert Waytulonis, Center for Diesel Research, University of Minnesota
>
> "Water scrubbers are not a pollution control, they are a fire control system ... , but scrubbers create condensation in the air and increase mine air humidity ... and with several pieces of diesel equipment using water scrubbers {on a section}, the increased heat effect because of the humidity is a significant concern ...." - Joe Main, United Mine Workers of America

The ***exhaust location*** can make a big difference in the concentration of pollution to which equipment operators and nearby miners are exposed. The location should be such that exhaust is directed away from the vehicle operator's position. The exhaust gas can be directed across the radiator, thus providing immediate dispersal by the radiator fan, or an ***exhaust extender*** can be used to redirect the exhaust away from the operator or nearby miners. ***Fume dilutors*** can also be used in vented headings and tunnels.

> "Wouldn't it be nice if we could take that exhaust and put it somewhere else on the vehicle, so then, at very least, the Ramcar operator is not subject to his own vehicle's emissions?" - Jan Mutmansky, Ph.D., Pennsylvania State University

Exhaust filtration devices capture DPM from the exhaust before it enters the mine atmosphere. Filters used to capture particulate or other exhaust constituents are called "***aftertreatment devices***." The most commonly used exhaust filtration devices are: ***disposable diesel exhaust paper filters, catalyzed or uncatalyzed diesel particulate ceramic filters, and a variety of reusable filters***.

Particulate control systems utilizing these components typically have removal efficiencies ranging between 50 and 95 percent, that is, they remove 50-95% of the particulate. It is important to note that an aftertreatment device that is 90 percent efficient is twice as effective for removing DPM as an 80 percent efficient device. This is because 10 percent instead of 20 percent of the particulate would remain in the exhaust.

The ***disposable diesel exhaust filter*** is similar to the intake air filter used on over-the-road haulage vehicles. It is placed downstream of a water scrubber or a water jacketed heat exchanger capturing DPM from the exhaust stream. The filter is discarded after being loaded with DPM. (Check state requirements for any disposal restrictions. In Pennsylvania, for example, the loaded filters have to be bagged and brought to the surface.) Tests of the disposable diesel exhaust filter at two underground coal mines resulted in 70 to 95 percent reduction in DPM. Commercial systems are currently available. Utilization of different filtration media and careful application of these filters combined with cleaning and reuse can extend the life of the filters. Also, proper maintenance of the water level controls in the scrubber will eliminate the risk of hot exhaust gases igniting the filter.

> "... Disposable paper filters are installed on the Ramcars such that the exhaust first passes through the water scrubber, then through a water trap or baffle system to prevent water droplets from being carried by the exhaust stream to the filter and then finally through the low-temperature paper filter. There's an exhaust temperature shutdown installed in front of the paper filter to prevent the exhaust gases from reaching 212° F, which is the maximum safe operating temperature of the filter. There's a backpressure gauge mounted in the operator's cab to help them know when the filters need to be changed out." - Bill Olsen, West Elk Mine, Mountain Coal Company.
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> "Today, the best strategy to use on a diesel Ramcar is to use the changeable paper filters that many mining companies are currently using." - Jan Mutmansky, Ph.D., Pennsylvania State University
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> "...The Ramcar operators quickly accepted the filters and wanted them installed on all the face equipment. We have since installed the disposable diesel exhaust filters on our Wagner 25xs, Teletrams and Petitto Mule...." "...We typically get about six hours off the Ramcar and Pettito Mules. On our Wagner systems we average approximately four hours of service life...."- Bill Olsen, West Elk Mine, Mountain Coal Company
>
> "...In our experience, the lifetime of the filters has varied anywhere from 8 hours to 32 hours -- provided that the engine on which the filter is installed is tuned properly so that it is not putting out too much soot. {The actual time between filter changes will vary depending upon the vehicle and engine's state-of-maintenance, duty cycle and other parameters.}" - Bob Waytulonis, Center for Diesel Research, University of Minnesota

The ***catalyzed or uncatalyzed ceramic diesel particulate filter*** has the potential to reduce DPM emissions from 60 to 90 percent. Exhaust passes through the ceramic or metallic diesel particulate filter which traps the particulate matter. As exhaust continues to pass through the filter, filtering continues, and the filter slowly becomes clogged with DPM. Clogging increases the exhaust backpressure which can lead to engine damage unless the exhaust backpressure is lowered by cleaning the filter.

Vehicles which have sufficiently high exhaust temperature, (at least 325EC , 25% of the time) can automatically clean the filter in a process called *autoregeneration* or self-cleaning. During autoregeneration the high exhaust temperature causes the trapped DPM to ignite and burn, thus reducing the exhaust backpressure on the engine and allowing more DPM to be trapped. For other vehicles, regeneration can be assisted by the application of a catalyst to the filter, which lowers the regeneration temperature, or by the use of on- or off-board regeneration systems.

> "There are approximately 1,000 diesel particulate filters presently {being used} on mining vehicles throughout the world." - Dale McKinnon, Manufacturers of Emission Control Association
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> "In 1989 Homestake initiated a test on ceramic wall flow diesel particulate filters. Eight units were tested on a Cat 3306, different loaders from three different suppliers. One failed right away and was replaced by the supplier. Five lasted on the average about 2,000 hours, and two went over 3,000 hours. Miner acceptance was good when the filters were working properly." - John Marks, Homestake Mining Company

Although ceramic diesel particulate filters are useful, they may present problems for some users.

> "... Number one, while ceramic filters give good results early in their life cycle, they have a relatively short life, are very expensive and unreliable. Number two, other post-combustion devices are not readily available for the larger horsepower production equipment we are currently using. When evaluated for lower horsepower support equipment, they appear to be very costly with no proven reliability..." - Ray Ellington, Morton Salt

Oxidation catalytic converters (OCCs) are used to reduce the quantity of carbon monoxide and hydrocarbons, including harmful aldehydes, in diesel exhaust. Oxidation catalytic converters also decrease the soluble organic fraction of DPM as well as gas phase hydrocarbons, which can reduce DPM emissions by up to 50 percent. The soluble organic fraction of the DPM exhaust contains known carcinogenic compounds such as benzo(a)pyrene and other polycyclic aromatic hydrocarbons.

Use of low sulfur fuel (<0.05 percent sulfur) with OCCs is critical because air quality is harmed when fuel containing moderate or high sulfur (>0.1 percent) is used. An OCC oxidizes sulfur dioxide to form sulfates which increase particulate emissions. OCCs can also oxidize nitric oxide to more harmful nitrogen dioxide. Modern catalysts are formulated to minimize the production of sulfate particulate matter and nitrogen dioxide, provided they are used with high quality low sulfur fuel.

The OCC should be located as close as possible to the exhaust manifold to ensure maximum exhaust gas temperature. The catalyst formulation and its operating temperature are critical factors in converter performance. The temperatures required for 50 percent conversion of carbon monoxide and hydrocarbons are typically about 370EF and 500EF , respectively. As higher exhaust gas temperatures are attained, conversion efficiency increases. The use of high sulfur fuel reduces the life of catalytic converters. New catalyst technology and the availability of low sulfur fuel make the use of OCCs on underground mine vehicles an attractive tool for reducing diesel particulate emissions.

> “There are also over 10,000 oxidation catalysts that have been put into the mining industry over the years.” ... “Sulfation is key in particulate control; you don't want a catalyst to cause any oxidation of the sulfur. I remember once I was in India, and there was a complaint that they put a catalyst on and they were saying it caused smoke. And it did, a lot of smoke. I took a fuel sample and the fuel had 2.2 percent sulfur in it, not 0.25 percent.” “... Engine, fuel and aftertreatment control technology must work together.” - Dale McKinnon, Manufacturers of Emission Control Association
>
> “The Homestake Mine has had extensive experience with oxidation catalysts ....We have always had them on our diesel units. And I know there's been a controversy on whether they might improve the work environment or harm it, but with low sulfur fuel I don't think there's any doubt they are a benefit. They oxidize the CO to CO_2, and they burn off some of the unburned hydrocarbons and some of the components of diesel exhaust. We like them. The {modern} catalytic purifiers, to my knowledge, limit the NO-to-NO_2 conversion, and with the low sulfur fuel you don't get the sulfates coming out. So we think we're better off with them." - John Marks, Homestake Mining Company

Dry system technology. An alternative to water scrubbers for meeting the exhaust gas cooling, spark arresting, and flame arresting requirements is the Dry System Technology (DST®). With this technology, the exhaust gas does not come into direct contact with cooling water, but is indirectly cooled by a water-cooled heat exchanger such as a tube and shell heat exchanger. This cooling process does not involve the evaporation of water. Spark and flame arrest are provided by mechanical means.

The DST® also includes a water-jacketed oxidation catalytic converter and a disposable diesel exhaust filter to reduce diesel emissions. The oxidation catalytic converter is located upstream of the water-cooled heat exchanger. Exhaust then passes through a water-jacketed heat exchanger, paper filter and flame arrestor. This system reduces diesel particulate by 95 to 98 percent. The DST® includes a complete set of diagnostic gauges to monitor system performance. The DST® has been approved by MSHA under 30 CFR Part 36. It can be used in coal or gassy metal and nonmetal mines where permissible equipment is required. In addition, the heat exchanger technology could be applied to nonpermissible engines in order to cool the exhaust gases so that disposable diesel exhaust filters (paper filters) could be used to reduce particulates.

“This system {the DST®}, I think, represents, from everything that I've seen, the state-of-art of the industry...the best technology on the market today....This gives us the ability for the first time in a long time to change direction and try to solve problems {with diesel exhaust}.” - Joe Main, United Mine Workers of America

The DST® has been tried on a number of vehicles retrofitted to use it. “... It was a welding truck, at Shoshone. It was put in 1992, November. That's coming up pretty close to three years. Has operated very successfully; have had no problems. There's a 913 scoop; that's at Twenty-Mile since January, 1994.... We retrofitted a 25X Wagner shield hauler....” - Norbert Paas, Paas Technology

Use of Ventilation

The primary means of reducing exposure to diesel exhaust pollutants underground is diluting exhaust pollutants with fresh air provided through the mine's ventilation system. The concentration of pollutants is inversely proportional to changes in ventilation air quantity, that is, as the air quantity increases the pollutant concentrations decrease. The mine ventilation system works in conjunction with the other methods of contaminant control such as maintenance, exhaust treatment, etc. Any control system must then be supplemented with checks to ensure that all aspects are working as designed. One way to check the control system is to conduct periodic sampling of diesel contaminants to detect changes in the system.

Mine ventilation systems where diesel engines are operated generally supply between 100 and 200 cubic feet per minute per brake horsepower (cfm/bhp). This air quantity is normally sufficient to dilute gaseous emissions from the diesel equipment to applicable standards for those gases. However, MSHA's experience in underground mines has shown that with these air quantities, DPM levels will still range between 200 $\mu g/m^3$ and 1800 $\mu g/m^3$ (as illustrated earlier in Figure 1). As a general reference, about 35,300 cfm of air is required to dilute one gram per minute of DPM to 1000 $\mu g/m^3$. Therefore, to optimize the reduction of DPM, it may be necessary to supply air quantities above those currently being used.

THERE ARE SPECIAL VENTILATION REQUIREMENTS WHEN DIESELS ARE USED IN UNDERGROUND COAL MINES. When a single piece of diesel equipment is operated, the nameplate airflow must be provided as a minimum airflow requirement. For each individual piece of diesel equipment operating in a coal mine, the approval plate quantity must be maintained in any working place where the equipment operates, at the section loading point, and in outby entries where the equipment operates. The MSHA regulations also allow the District Manager to add areas where the approval plate quantity may be required, such as fueling locations. When multiple pieces of diesel equipment are operated, the minimum section airflow is the sum of the nameplate airflows for the individual pieces of equipment. This requirement was developed to reduce the gaseous diesel emissions. However, not all equipment is operated on a continuous basis and some equipment, such as transportation and supply vehicles, may be excluded from this calculation. (Prior to the 1996 diesel powered equipment rule, a 100-75-50 percent guideline was used to establish minimum section air quantity requirements.) Any excluded equipment must be approved by the District Manager and listed in the ventilation plan for the mine. The intent is to allow for the exclusion of equipment that does not significantly add to the exposure of miners. These quantities must be maintained in the last open cross cut of working sections, the intake to longwall sections, and the intake to pillar lines. The multiple unit quantity also applies in the area where mechanized mining equipment is being installed or removed. Quantities other than the multiple unit formula can be approved by the MSHA District Manager if samples show that such reduced quantity will not result in overexposures.

> "...Ventilation can take care, in my opinion, of most diesel equipment in the main haulageway, even in the sub-mains. However, when you approach the face area, you don’t have that velocity and that quantity of air, then the control of engine exhaust may be necessary depending on the size of the engine and the concentration." - Pramod Thakur, Ph.D., Consol, Inc.

Metal and nonmetal mines can be ventilated in a variety of ways. In single level mines, working areas are generally ventilated in series. The exhaust of one area becomes the intake for the next area. Multilevel mines may provide a separate air split to each level or to several levels. Separation between intake and exhaust air courses is essential to prevent leakage or loss of fresh air. Auxiliary and booster fans should be installed throughout the mine to optimize distribution of workplace airflow.

Changing a mine's ventilation system to reduce pollutant exposure is frequently expensive and may require a long time to implement. Simple changes can include repairing an individual brattice or reducing leaks in an entire brattice line. However, significant improvements in air quality often are only achieved by complex changes such as redesigning the entire mining system to reduce airflow leakage, modifying the main fan installation, or adding a new air shaft.

> “The mine ventilation system must be designed to provide and distribute sufficient airflow to areas of the mine where diesel equipment is being used. Typical ventilation rates in metal and nonmetal mines range from 75 to 200 cfm per brake horsepower in use. In coal mines the name plate airflow has been used to determine plan airflow requirements.” - Robert Haney, Mine Safety and Health Administration
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> “Ventilation continues to be an important method of controlling diesel particulate matter concentrations, and our studies have shown that significant reductions can be achieved by changing the ventilation around in the section.” - Jan Mutmansky, Ph.D., Pennsylvania State University
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> “Ventilation still remains the vanguard against diesel emissions. Toward the end of 1992 we reduced overall airflows to cut costs as part of a mine optimization process, and this summer we returned those airflows. We currently have a mine migration of about 115 cfm/bhp. We designed with the 100-percent rule. We don't use 100 percent, 75 and 50 percent thereafter, although that's the way it sometimes works out. We try and keep all of our diesels on parallel splits as much as possible.” - John Marks, Homestake Mining Company
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> “All permissible diesel face equipment is ventilated according to MSHA-required nameplate values. These are usually required to make in excess of 18,000 cfm in the last open break and 40,000 cfm on the section. In normal operation these values are 35,000 cfm in the last open break and 45,000 on the section.” - Chris Pritchard, Tg Soda Ash Company

"Looking a little closer at ventilation, in one of our larger panels, typically at any one time you'll see three Ramcars at 139 horsepower operating, a roof bolter, a powder wagon and roughly two service vehicles ... for more or less a total horsepower of ... 610. With an air volume of 100,000, we have an effective air-to-horsepower ratio in an operating panel of 164. If you look at the entire mine, installed horsepower, the air-to-horsepower ratio is about 95. New Mexico has a standard of 75, so we're somewhat better than that." - Scott Vail, Ph.D., IMC Global Carlsbad Mine

"We control air flow in the mine using air doors and air walls." ... "We generally will shotcrete or gunite the leakage to prevent leakage in those areas. We build air walls throughout the mine. We just pile up waste rock in the crosscuts to a certain point. We use old conveyor belt in the mine. We cut that in strips, fold it to the back, overlapping, and that produces a very efficient air wall in the mine." - Regina Henry, Dravo Lime Company, Maysville, Division

"Our stoppings consist of brattice cloth or waste salt piled to within 10 foot of the roof and brattice cloth. We have auxiliary fans located throughout the mine that mix the gases as they come off the sections. Our main intake ventilates all of the sections in B-bed, then returns to the production shaft. Right now our C-bed is on its own split of air, and we continue to keep it that way." "Several years ago when our fans were old and running at a maximum capacity, we decided...to see what we needed to do to build a better ventilation system. We conducted several pressure and air quality surveys, and the results were put into a computer simulation model. From this model, we found out that we definitely needed new fans...." "We also decided that when we were developing C-bed, that we did not want to continue with the way we were currently ventilating the mine. In other words, we did not want to have one single split ventilating all the sections. So at that time we sat down and we worked out a way to ventilate each section on its own separate split, which is what most coal mines do. We feel that this will give us a better air quality, we will be able to see it, and it will help clear the air out faster." - David Music, Engineering Manager, Akzo Nobel Salt's Cleveland Mine

"...We believe mine design and ventilation is an important ... control. The fact of the matter is, though, that... mine ventilation is not a stand alone system {for reducing exposure to diesel emissions}...."Even coupled with the water scrubber exhaust cooling systems that have become the industry standard, we haven't reduced particulate exposure to {what we would consider} an acceptable level...." - Jeff Duncan, United Mine Workers of America.

Use of Enclosed Cabs

Properly designed and maintained environmentally conditioned cabs can reduce the exposure of equipment operators to diesel emissions. Cabs should be pressurized and use high-efficiency particulate air (HEPA) filters. Many surface mines are currently using properly designed environmentally conditioned cabs. Some efforts are being made to use enclosed cabs on underground mining equipment. The same principles apply to the use of underground booths designed to protect miners.

> "I recently completed a study of a surface coal mine, and they were using pressurized cabs to minimize exposures...." Has this been given some thought in your design [of Ramcars] at Jeffrey?...." - Robert Wheeler, Consultant // "We may be getting very close to that, because just recently we produced the first Ramcar-type of vehicle ever with a cab, with some climate controls."... "One of the problems with exposure in underground mines is not the operator of the machine. Because of the close confines, it's the people around the equipment and, of course, the pressurized cab does not affect them at all." - John Smith, Jeffrey Mining Products

Diesel Engine Maintenance

Engine maintenance is an important part of a mine's overall strategy for reducing workers' exposure to diesel emissions. Without proper maintenance, diesel engines will perform poorly, thus reducing the effectiveness of all other emission control strategies.

> "It has been definitively proven, that when engine maintenance is neglected (especially if it involves regulating the fuel and air handling systems of engines) the particulate, and carbon monoxide, and hydrocarbons, all skyrocket." - Robert Waytulonis, Center for Diesel Research, University of Minnesota
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> "...We had a lack of maintenance on these pieces of diesel equipment. They were running the equipment until they broke down, and they would fix them, and they would run them again until they broke down ..." - Glen Pierson, Alabama Coal Miner (UMWA)
>
> "We're having problems with respect to maintenance of diesels. We're having problems with untuned diesels. When we go to do longwall moves, we're working in an environment where the blue smoke is so heavy sometimes you can't see. We don't have a good maintenance system. We don't have a good inspection system." - Joe Main, United Mine Workers of America

A good preventive maintenance program will maintain near-original performance of an engine, and maximize vehicle productivity and engine life, while keeping exhaust emissions down. Engine maintenance activities which should be performed by mine maintenance personnel include maintenance of the following systems: air intake, cooling, lubrication, fuel injection and exhaust. These systems must be maintained on a regularly scheduled basis to keep the system operating efficiently. Measuring tailpipe CO emissions while the engine is under load provides a good check on whether the maintenance program is working. In addition, vehicle operators should make daily checks of engine oil level, coolant, fuel and air filters, water tank, exhaust piping and gauges. There are very specific requirements for maintenance of diesel equipment in underground coal mines; some are noted below.

The ***air intake system*** removes airborne particles before they enter the engine and cause abrasion of internal engine surfaces. Intake air filters should be replaced when the pressure drop indicator exceeds the manufacturers' specifications, usually 20 to 25 inches of water. As of November 25, 1997, for diesel-powered equipment used in underground coal mines, intake air filters must be replaced or serviced when the intake air pressure device so indicates, or when the engine manufacturer's maximum allowable air pressure drop level is exceeded.

> "...Maintenance is extremely critical." ... "It takes two days to screw up the engine in the mine if you're running without an air cleaner or a clogged air cleaner or a cleaner was replaced by the wrong cartridge element that allows for some air to bypass the fuel filter." - Jamie Sauerteig, Deutz Corporation
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> "One of the most simple things in maintenance is the intake air cleaner or filter. You could have emission increases by as much as 300 or 400 percent just having a clogged intake air cleaner."- Norbert Paas, Paas Technology
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> "Maintenance: intake air and exhaust systems are checked at least once each day during their operation. Inspections are completed on a weekly basis. Inspections are done by competent persons assigned by the company to perform that work, and inspections are completed in a well-ventilated area." "Results of these daily and weekly inspections are kept in a permanent record book ..." - Steve Biby, Old Ben Coal Company

The ***cooling system*** directly affects engine emissions by preventing scuffed cylinder walls and pistons, cracked heads, and burned valves. Liquid-cooled engines must be kept free of mineral deposits and rust to ensure effective heat transfer. Mine water is generally high in minerals and salts, rendering it unfit for use in the cooling system. A 50 percent antifreeze and distilled water solution is optimal. Cooling fans, ducts and cowlings must also be maintained to ensure adequate cooling.

Air-cooled engines discharge heat via cooling fins, and liquid-cooled engines rely on radiators. Cooling fins and radiators must be kept free of oil and dust, and not be damaged to ensure proper heat transfer. Slipping fan and pump belts must be replaced to ensure proper air and coolant flow, thus avoiding excessive heat buildup.

The ***fuel injection system*** can be damaged by contaminated fuel. To prevent this damage, fuel filters should be regularly replaced and fuel tanks should be periodically drained and cleaned. Fuel should be properly handled and dispensed to avoid contamination. The number of fuel transfer points should be minimized to avoid contamination during unnecessary fuel transfer. Fuel tanks should be kept as full as possible to prevent condensation of water in the tank. Water should not be allowed to condense in fuel storage tanks. Water can be removed by the installation of fuel-water separators at the outlet of the surface storage tank, on the pump side of portable fuel trailers and on all engines. Water-absorbing additives may also be used.

The fuel injection pump should be set to the engine manufacturer's or MSHA's specifications prior to running the engine at the mine. In addition, the mine elevation must also be considered in the final adjustment of the fuel injection pump. Air density decreases with an increase in elevation; therefore the fuel-air ratio will change as elevation increases, thus causing an adverse effect on the engine emissions. If the engine is operated at elevations above 1,000 ft, the fuel rate should be reduced as specified by MSHA or the engine manufacturer. Turbocharged engines are an exception to this rule due to excess quantities of air available from the turbocharger. MSHA or the engine manufacturer specifies the maximum operating elevation of a turbocharged diesel. Above this elevation, engine deration is necessary.

Caution should be observed in trying to increase the power output of engines: following manufacturer specifications can avoid significant increases in pollution. Minor increases in power that can be produced by adjusting the fuel-air ratio can also produce significant increases in particulate emissions, as can too much advance or retardation of the fuel injection timing.

The locks and seals on the fuel pump and governor must not be tampered with or removed. Faulty adjustment can result in overfueling and engine damage. Over fueling can increase emissions, especially black smoke, carbon monoxide, and particulates.

> {Engines used at high elevation must be properly sized to ensure adequate power.} "Due to our elevation of approximately 7,000 feet, the 150-hp engines are derated to approximately 115 hp. Unfortunately, horsepower at the wheels on the Ramcars is down to about 90 hp." - Bill Olsen, Mountain Coal Company, West Elk Mine
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> "...The best way to reduce these particulate emissions is to get the fuel injector pumps and the fuel injectors properly adjusted so they do not overfuel the engine. That will bring the particulate emissions down faster and more effectively than anything else..." "It will also lower hydrocarbon and carbon monoxide emissions...." - David Hofeldt, Ph.D., University of Minnesota

Failure to maintain the ***lubrication system*** can lead to significantly increased particulate emissions, and eventually to catastrophic engine failure. Worn valve guides and piston rings allow lube oil to leak into the combustion chamber and cause white and/or blue-black smoke, and the creation of significant particulate concentrations. System failures are often caused by a component failure, such as seized bearings, lubricant breakdown, lubricant contamination or engine overheating. To prevent these failures it is important to regularly replace oil filters, maintain crankcase lubricant at the recommended levels and to maintain the engine's cooling system. Excessive heat lowers the viscosity of engine oil and results in lost lubricity and accelerated engine wear. The quality of the lubrication oil is also important and contamination must be avoided.

> "... Any engine, regardless of whether it has mechanical controls or a sophisticated engine with electronic controls, if the engines have not been maintained, if they're burning oil, you will get plenty of blue smoke of all kinds." ... "I think we tend to confuse blue and black smoke sometimes." ... "But generally a blue exhaust gas will indicate oil consumption, typically low load operation, high oil consumption. Black smoke is more related to overfueling. In other words, we're talking about full load overfueling of the engine, high temperature. It's basically the opposite of blue smoke." - Jamie Sauerteig, Deutz Corporation

The ***exhaust system*** must be periodically inspected and maintained to avoid the buildup of excessive exhaust backpressure and to ensure safe operation of the engine. Backpressure increases may result from a partially plugged water scrubber, flame trap, OCC, filter or dented exhaust pipe. Increased backpressure causes increased emissions and reduced performance. Back pressure should not exceed 27 to 40 inches of water or manufacturers' specification.

The tanks of water scrubbers used on permissible equipment must be filled and the float valves must be operational to meet MSHA safety requirements. Proper maintenance also ensures safe operation of the disposable diesel exhaust filters located downstream of the scrubbers.

> "Water scrubbers are prone to mechanical failures, prone to maintenance problems. You can lose water, you can have a filter catching fire, very unreliable." - Mridul Gautam, Ph.D., West Virginia University

A diesel engine operates over a wide range of duty cycles. The most accurate way to assess the content of exhaust emissions during actual mining conditions is to take ***tailpipe samples while the engine is under load***. Weekly tests for CO in the undiluted exhaust are required for certain types of diesel-powered equipment in underground coal mines as of November 25, 1997.

A gas monitor can be used to measure the carbon monoxide level in the raw exhaust. A large increase in the carbon monoxide concentration is an indication that the engine has a maintenance problem that needs to be addressed. An increase in the carbon monoxide concentration is also a good indication that the diesel particulate concentration and observable smoke levels are increasing. Regular testing of these engines will provide information on the need for maintenance.

Engine emissions during mining operations cannot be accurately evaluated at idle conditions. On certain types of mine vehicles, like load-haul- dumps (LHDs) and scoops, a repeatable loaded condition can be readily placed on the engine. On clutched vehicles and generator sets, this may not be possible.

..."At our mines, we've got a multi-gas testing system hooked up through... our mine monitor system, and from what I understand, unless you test these vehicles under load, it's more or less useless; is this correct?" - Morris Ivie, Alabama Coal Miner (UMWA) // "...Well, {yes}... just about." - Mridul Gautam, Ph.D., West Virginia University

"...By tuning the engines on the dynamometer and making sure that we get the rated performance, the amount of smoke is greatly reduced, essentially eliminated." - Scott Vail, Ph.D., IMC Global Carlsbad Mine

Diesel engine maintenance is the cornerstone of a diesel emission control program. Proper maintenance includes ***compliance with manufacturers' recommended maintenance schedules, maintenance of accurate records and the use of proper maintenance procedures***. Inadequate maintenance, improper adjustments, wear, and other factors will cause changes in diesel exhaust emission rates. Diesel engines in underground coal mines must be maintained in compliance with the conditions of the MSHA approval, and examined weekly in accordance with approved checklists and manufacturer maintenance manuals as of November 25, 1997.

"...To control DPM, we've got a good strong preventative maintenance program. We bring equipment in on a regular basis on the 50, 250 and 1,000-hour intervals and do the recommended filter checks and changes as recommended by the manufacturer." - Denny Alderman, Turris Coal Company

?...I just want to stress the importance of a good maintenance program... We have a very good maintenance program in that it's preventive maintenance as well as, you know, when problems arise on the job, we just get it fixed." - William Cranford, UMWA Safety Committeeman

"...A well-conceived maintenance program strives to maintain optimum engine performance and thereby control diesel exhaust emissions. The maintenance program consists of regularly scheduled replacements of fluids and filters, operating performance evaluations and additional weekly permissibility inspections, ... and a training program to educate maintenance personnel in the engine operating recommendations and requirements." - Keith Roberts, Kerr McGee's Galatia Mine

"The mine currently used about 115 pieces of diesel equipment ...." "Although the mine has been slowly downsizing over the past five years, the number of diesel mechanics has increased, and we do this because we've upgraded our preventative maintenance. We seldom see a smoking diesel underground anymore, although once in a while, of course, we get one." - John Marks, Homestake Mining Company

> "There's a whole section in the MSHA advisory standards on diesel maintenance almost from A to Z. It could be almost verbatim from manufacturers' manuals themselves.... They've been laying in front of mine operators' faces for 15, 16 years now. Some of them {mine operators} adhere to them religiously. Others have never even seen the standards, either voluntary or mandatory, have never even opened that section of the book." - Harry Tuggle, United Steelworkers of America

It is worth emphasizing that to if repairs and adjustments to diesel engines are to be done properly, ther personnel performing such tasks must be **properly trained**. OPERATORS OF UNDERGROUND COAL MINES WHERE DIESEL-POWERED EQUIPMENT IS USED ARE REQUIRED, AS OF NOVEMBER 25, 1997, TO ESTABLISH PROGRAMS TO ENSURE THAT PERSONS WHO PERFORM MAINTENANCE, TESTS, EXAMAINATIONS AND REPAIRS ON DIESEL-POWERED EQUIPMENT ARE QUALIFIED.

> "I think the mechanics need to be trained so they understand exactly what causes the emissions." - Norbert Paas, Paas Technology
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> "It's also fundamental that the mechanics have proper and modern tools at their disposal and be trained in how to use them." - Robert Waytulonis, Center for Diesel Research, University of Minnesota

Work Practices and Training

Work practices and training can have a significant effect on diesel exhaust emissions.

Care must be taken to avoid contaminating diesel fuel and lubricating oils during transfer. Fuel contamination can result from transfers taking place in a dusty and damp environment or by simply using the same transfer pump for multiple fluids. Fuel contamination will increase emissions.

Operators should avoid lugging the engine to low RPM. Lugging an engine is applying an increasing load (torque) against the engine, while the engine's fuel rack is at the maximum position, causing a decrease in the engine's RPM. An example of lugging is when a LHD operator drives the bucket into a muck pile with the accelerator to the floor and continues to work the engine causing the engine's RPM to decrease. If the engine operator continues to work the engine to a point where the engine's RPM are low but the torque demand on the engine is high, the engine may eventually stall. However as the engine's RPM decrease and the engine torque increases, the engine's ability to efficiently burn fuel decreases causing the engine to produce excessive carbon monoxide and particulate emissions. For naturally aspirated engines and older turbocharged engines, an engine operating at a lower RPM and high load produces higher exhaust emissions than an engine operating at a higher RPM and lower load. To avoid this situation, a vehicle operator should maintain a higher engine RPM while performing the work. This might mean picking up a smaller load or carrying less material or shifting to a lower gear. The result will be a reduction in engine exhaust emissions.

Operators should avoid idling the engine. Idling wastes fuel, increases emissions and may overcool the engine. Overcooling results in incomplete combustion, higher emissions and may lead to varnish and sludge formation. Unburned fuel washing down cylinder walls removes the protective film of lubricating oil and results in accelerated wear. The fuel dilutes the lubricating oil resulting in reduced lubricity. Engines should be shut down and not idled except as required in normal mining operations. AS OF APRIL 25, 1997, IDLING OF DIESEL-POWERED EQUIPMENT, EXCEPT AS REQUIRED IN NORMAL MINING OPERATIONS, IS PROHIBITED IN UNDERGROUND COAL MINES.

Operators of diesel-powered equipment must be trained on the operation of the equipment and in routine inspection and maintenance activities. For instance, operators should carry spare intake air filters, so that clogged filters can be changed as needed. AS OF NOVEMBER 25, 1997, OPERATORS OF MOBILE DIESEL-POWERED EQUIPMENT IN UNDERGROUND COAL MINES MUST CONDUCT A VISUAL EXAMINATION OF THE EQUIPMENT BEFORE PLACING THE EQUIPMENT IN OPERATION.

> “Our operators all undergo a six-week training period underground on a training panel learning to efficiently and safely operate the equipment before we turn them loose in a production panel. A big part of that is awareness and reporting. They get on equipment, the power drops off or it's smoky, they know they're supposed to report it, and we do something about it. If air volume's dropping off, it's probably because the ventilation crew hasn't kept with the panel. It's reported, we address it. So we stay on top of things.” - Scott Vail, Ph.D., IMC Global Carlsbad Mine
>
> “We need education, education, education of the people who operate the equipment, of the people who maintain the equipment...and of the people that inspect the equipment for the enforcement agencies. A complete education process should start tomorrow.” - Joe Main, United Mine Workers of America
>
> “Equipment operation -- my key thing is operators' training -- to make the operator aware of exactly what a diesel machine is, what to look for, give them the ability to diagnose problems on the machine so that when he sees something, he can make a decision -- should I call a mechanic in or not? Very important in the program. And a walk around inspection? -- It takes less than five minutes." - Norbert Paas, Paas Technology

Operators and maintenance personnel should read and be familiar with the manuals covering the machines they operate and maintain. Besides specifying how a machine is to be operated and maintained, these manuals provide useful information on servicing methods and intervals.

Fleet Management

Diesel fleet management includes setting policies for operator and mechanic training, diesel usage, engine replacement and determining the types, numbers and horsepower of diesel engines used underground. Establishing such policies, and purchasing the needed equipment, is usually the role of upper mine management. Several participants at the MSHA workshops stressed that these management activities could play an important role in reducing diesel emissions. They suggested that mine management must actively support operator and mechanic training and ensure that adequate shop facilities are available to maintain the diesel fleet.

> "...We have service areas that advance with the panels underground because we're so spread out, and our main rebuild shop is also underground...." - Scott Vail, Ph.D., IMC Global Carlsbad Mine

Respiratory Protective Equipment

While it should NOT be used as the primary method of control, use of respiratory protective equipment can reduce miner exposure to DPM.

It is generally accepted industrial hygiene practice to eliminate or minimize hazards before resorting to personal protective equipment. As indicated by the quotations in this toolbox, various mines are taking a variety of approaches to minimize DPM emissions and to reduce DPM concentrations in mine atmospheres. However, requiring the use of the correct respiratory protective equipment in areas of the mine which are difficult to ventilate and are currently subject to high concentrations of diesel pollutants can help to protect miner health.

> "Now, even before mechanization, slusher operators at Homestake wore half-face respirators as protection against the silica dust. Loader operators also are required to wear them. And with the organic mist and fume cartridges and filter pads, we figure that's removing 99 percent of any diesel particulate matter in the air." - John Marks, Homestake Mining Company

MEASURING THE CONCENTRATION OF DIESEL PARTICULATE MATTER IN MINES

Measurement of DPM in the workplace is important to determine occupational exposure and to evaluate how effective the control technology is. Periodic DPM measurements are an important part of a mine's overall program to reduce exposure to diesel pollutants.

Various methods for measurement are described in Appendix C of this publication.

> "...The ultimate measure ... is what the air quality is in the workplace, and I think that's an issue that we need to also consider. Just having cfm blowing through a place really doesn't give you the true picture....I want to be able to do the measurement on an ongoing basis..." - Dan Steinhoff, ASARCO
>
> "The Bureau of Mines, MSHA, NIOSH and others have been working with sampling technology that's been done in a prototype phase strictly within government control. We need to take that technology and get it out in the field so people can evaluate what their own exposures are and evaluate how they might reduce those exposures." - Mark Ellis, U.S. Borax Inc.

Mine operators who would like assistance in measuring or evaluating DPM exposures may request help from MSHA's Technical Support unit by contacting the MSHA District Manager in their area.

A DOZEN WAYS TO REDUCE EXPOSURE TO DPM

1. ***Use low emission engines.*** Older engines should be replaced with modern, low emission engines whenever possible, and new diesel equipment should be powered by low emission engines.

2. ***Use low sulfur fuel.*** Low sulfur fuel extends engine life, reduces emissions and allows catalyzed emission control devices to perform properly.

3. ***Use*** appropriate ***exhaust after treatment devices*** such as filters and oxidation catalysts***, and environmentally conditioned, enclosed cabs,*** where possible.

4. ***No ventilation, no operation.*** If ventilation in an underground mine is interrupted for any reason, all diesel equipment should be shut down.

5. ***Train miners properly.*** Miners must learn to recognize hazards, and to correctly operate and maintain diesel equipment. Designated maintenance personnel should be specially trained in diesel repair.

6. ***Read operation and maintenance manuals.*** Deviation from maintenance and operation schedules and procedures will increase emissions.

7. ***Beware of black smoke.*** Black smoke from a diesel engine is a result of improper fuel to air ratio. Black smoke indicates that engine maintenance is needed.

8. ***No unnecessary idling.*** Idling wastes fuel, increases emissions, and may overcool the engine resulting in increased wear.

9. ***Keep it clean.*** Dirt and dust are detrimental to engines. Periodic maintenance of the intake air system is required for peak engine performance. The air cleaner must be changed to avoid an intake air restriction that will increase emissions.

10. ***Keep it cool.*** Engine overheating is a frequent cause of premature engine failures. Ensure that the lubrication oil is the correct viscosity and kept at the recommended levels, and that heat exchangers are clean and damage free.

11. ***Operating the engine at high load and low speed (lugging) increases emissions.*** Operators should shift gears to operate the engine at higher speed to lessen the engine load.

12. ***No overpowering.*** The fuel injection pump governor must be set according to manufacturer's specifications or MSHA requirements. Tampering with the fuel system to boost power must be avoided.

APPENDICES

Appendix A: Recommended Additional Reading

1) Background

Health Effects Institute. Diesel Exhaust: A Critical Analysis of Emissions, Exposure and Health Effects. April 1995.

(For a copy contact the Health Effects Institute, 955 Massachusetts Avenue, Cambridge, MA 02139, or by calling 617-876-6700.)

Mine Safety and Health Administration, report of the Advisory Committee on Diesel-Powered Equipment in Underground Coal Mines, 1988.

(For a copy, available at cost, contact: MSHA, Office of Standards, Regulations and Variances, Room 631, 4015 Wilson Boulevard, Arlington, Va. 22203-1984, or call 703-235-1910.)

2) Controls

Mine Safety and Health Administration, transcripts of three workshops on Diesel Particulate control methods, Fall 1995.

(For a copy, on paper or disk, available at cost, contact: MSHA, Office of Standards, Regulations and Variances, Room 631, 4015 Wilson Boulevard, Arlington, Va. 22203-1984, or call 703-235-1910.)

U.S. Bureau of Mines. Diesels In Underground Mines: Measurement and Control of Particulate Emissions. IC 9324, 1992. 132 pages.

(To receive a free copy contact Robert Waytulonis, University of Minnesota Center for Diesel Research, Department of Mechanical Engineering, 125 ME, 111 Church Street, S.E., Minneapolis, MN 55455 or call 612-725-4760, x4760.)

Waytulonis, R. W. Diesel Exhaust Control, Chapter 11.5. SME Mining Engineering Handbook, 2nd Ed. v. 1. H. L. Hartman, ed., 1992, pp. 1040-1051.

3) Measurement techniques

Cantrell, B. K., K. L. Williams, W. F. Watts, Jr., and R. A. Jankowski. "Mine Aerosol Measurement", Chapter 27 in Aerosol Measurement: Principles, Techniques, and Applications, ed. K. Willeke, and P. A. Baron. Van Nostrand, 1993, pp. 591-611.

Haney, R.A., Saseen, G.P., and Waytulonis, R.,W., "An Overview of Diesel Particulate Exposures and Control Technology in the U.S. Mining Industry," Proceedings of the 2nd International Conference on the Health of Miners, Pittsburgh, PA., November, 1995.

Haney, R.A., and Fields, K.G., "Diesel Particulate Exposures in the Mining Industry, " MINE Expo International '96, Las Vegas, NV, September 10, 1996.

Gangal, M.J., and Dainty, E.D.,"Ambient Measurement of Diesel Particulate Matter and Respirable Combustible Dust in Canadian Mines," Proceeding of VIth U.S. Mine Ventilation Symposium, Salt Lake City, Utah, 1993.

Gangal, M.J., Ebersol, J., Vallieres, J., and Dainty, D., "Laboratory Study of Current (1990/91) SOOT/RCD Sampling Methodology for the Mine Environment, " Mining Research Laboratories, Canada Centre for Mineral and Energy Technology, MRL 91-000510p, Ottawa, Canada, 1990.

Appendix B: Glossary of Terms

After treatment devices - Devices such as filters which remove constituents of diesel exhaust as they leave the equipment.

Aftercooling - Cooling intake air prior to induction into the combustion chamber to increase power and reduce the emission of oxides of nitrogen.

Approval plate quantity - The quantity of ventilating air given in cubic feet per minute (cfm) that will dilute the concentrations of gaseous exhaust contaminants from a single diesel engine to specified limits for CO_2, CO, NO and NO_2. This is sometimes called the *nameplate quantity*.

Aromatic content - Hydrocarbons in diesel fuel are numerous but generally fall into three families: paraffins, naphthenes and aromatics. Reducing fuel aromatic content will reduce hydrocarbons in the exhaust and the organic portion of DPM.

Autoregeneration - Self-cleaning of a filter by an engine which has high enough exhaust temperatures to oxidize the diesel particulate matter captured on the filter. See *"regeneration"* below.

Exhaust Back pressure - the buildup of pressure against the engine created by the resistance of the exhaust flow passing through the exhaust system components.

Cetane number - The cetane number describes the ignitability of diesel fuel. Fuels with high cetane numbers have low self-ignition temperatures. Fuels with low cetane numbers cause engine roughness.

Cloud point - The cloud point is the highest temperature at which the first trace of paraffin visibly separates from the fuel.

Diesel particulate matter - Generally refers to the small particles of matter produced by diesel exhaust, which can be collected on filters. The term is abbreviated as DPM. The term "diesel particulate", or "DP", means the same thing.

Elemental carbon - Elemental carbon is sometimes used as a surrogate measure for DPM. It is composed of graphitic carbon, as opposed to organic carbon, and usually accounts for 40 to 60 percent of the DPM by mass.

Fuel-to-air ratio - the ratio of the amount of fuel to the amount of air introduced into the diesel combustion chamber.

Gm/hp-hr - Gram per horsepower-hour: The hourly mass of a contaminant in diesel engine exhaust emissions divided by the engine horsepower.

Impactor - Device used to separate particles by size using their inertial characteristics.

Nameplate quantity - Another term for approval plate quantity.

Permissible - As applied to diesel powered mining machinery, refers to a piece of equipment on which safety components and temperature controls have been added to prevent the ignition of methane or coal dust so that it can be safely used in areas of an underground mine where methane is likely to accumulate (i.e., face areas).

Regeneration - The process of oxidizing DPM collected on a diesel exhaust particulate filter. This process cleans the filter and reduces backpressure to acceptable limits.

Respirable combustible dust (RCD) - A method of measuring DPM using a combustion process.

Threshold limit value (TLV®) - The time-weighted average concentration (established by the American Conference for Governmental Industrial Hygienists) for a conventional 8-hour workday and a 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

Turbocharge - The process of increasing the mass of intake air by pressurization to the engine which allows more fuel to be burned and results in increasing the engine's power output.

Volatility - Volatility is a measure of the distillation rate of a fuel.

Wax separation - The separation of the paraffinic portion of diesel fuel at low temperature which can cause fuel flow problems.

Appendix C: Methods of Measuring Diesel Particulate Matter

DPM is comprised of solid elemental carbon particles, with adsorbed and condensed hydrocarbons and sulfates. The particles are arranged in chain aggregates that have a mass median diameter of about 0.2 micrometers. Several methods are available for determining DPM concentrations in the environment. They include:

! Measuring the mass concentration (gravimetrically) of the submicrometer portion of the respirable fraction of the aerosol.

! Measuring the mass concentration (chemically) of the elemental carbon in either the submicrometer portion of the respirable dust aerosol or in the respirable dust aerosol.

! Measuring the mass concentration (gravimetrically) of the respirable combustible fraction of the aerosol (often referred to as the RCD method).

Measuring the mass concentration of the submicrometer portion of the respirable dust sample is the most common method currently being used to determine the DPM concentration in coal mines. This method takes advantage of the facts that DPM is generally less than 0.8 micrometer (Fm) in size and that other dust collected in a respirable dust sample is generally greater than 0.8 micrometer in size.

Figure 2 shows a schematic of a sampling device that can be used to collect the submicrometer fraction of the respirable dust aerosol. The sampling device is similar to the standard respirable dust sampling device, which consists of a 10 mm nylon cyclone and a sample collection filter. However, the sampling device has been modified to incorporate an inertial impactor that separates particles greater than 0.8 micrometer in size out of the aerosol sample. Particles greater than 0.8 Fm are collected on an impaction plate. The submicrometer fraction (particles less than 0.8 Fm in size) is collected on the filter. Depending on the type of filter used to collect the submicrometer fraction, the collected sample can be analyzed gravimetrically to determine the DPM concentration or chemically to determine the elemental carbon concentration of the environment.

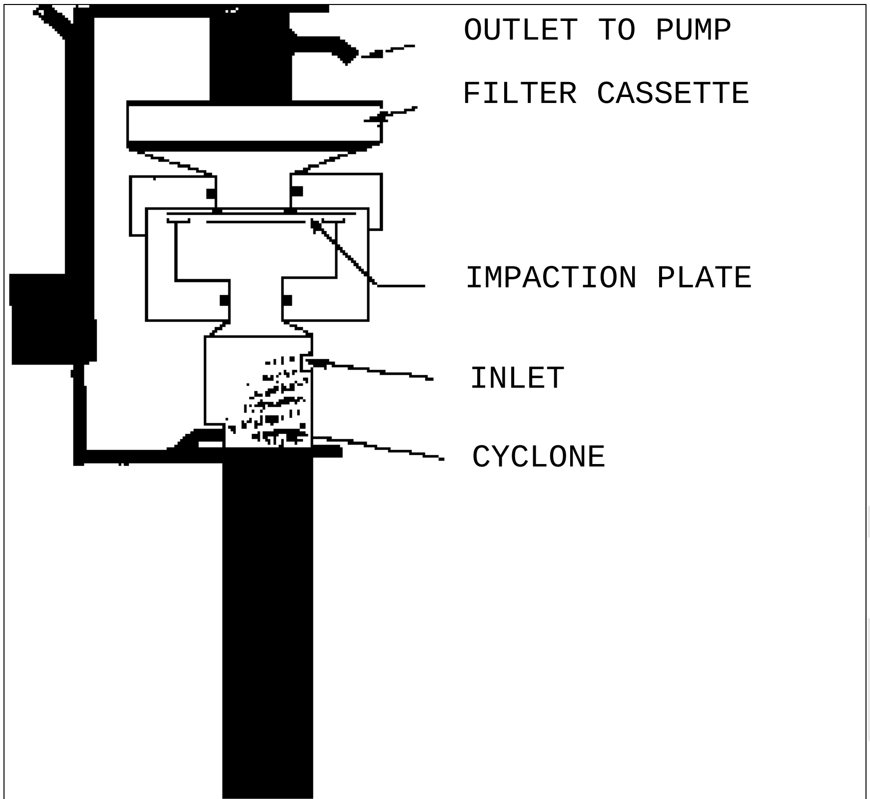

Figure 2-Personal Sampler Adapted for Submicron Sampling

For gravimetric analysis, the sample should be collected on a preweighed 5.0 µm pore size, vinyl Metricel filter. When the submicrometer mass of the sample collected is less than 0.3 mg the DPM should be determined using chemical analysis. For the chemical analysis a preconditioned (heated at 400 EC for 1 hour) quartz fiber-filter should be used. The elemental carbon content of samples collected on quartz-fiber filters can be determined using NIOSH's Elemental Carbon Method 5040. For metal and nonmetal mining operations, samples for elemental carbon analysis can be collected either with or without the impactor.

It should be noted that gravimetric analysis of the submicrometer mass fraction is not equivalent to the elemental carbon mass fraction unless the organic mass fraction is also included in the analysis. Although nearly all elemental carbon present in underground mine atmospheres is attributable to diesel exhaust, this is not necessarily the case for the organic carbon fraction where other sources such as drill oil mist, coal dust and cigarette smoke are present.

The RCD method is applicable to certain metal and nonmetal mining operations. For the RCD method, the aerosol sample is collected using the standard respirable dust sampler. The sample can be collected with or without the impactor. To measure the mass concentration of DPM, the respirable sample is collected on a preweighed, 0.8 Fm pore size, silver membrane filter. The filter is preconditioned by heating at 400EC in an oven. After sample collection, the filter is again heated at 400EC in an oven to burn off the carbonaceous material and weighed. The loss in sample mass resulting from the heating represents the DPM.

The RCD method should be used with caution when a hydrated mineral dust (e.g., gypsum or trona) or a carbonaceous material (e.g., drill oil mist) collects on the filter. Such materials are chemically altered by the heating process and produce erroneous results unless properly accounted for.

Each of the three methods has been used to determine the concentration of DPM in underground mines. Studies of these methods have shown that DPM concentrations determined from gravimetric analysis of the submicrometer fraction of the respirable dust aerosol are approximately the same as those determined using the RCD method; and, that elemental carbon concentrations determined from either the submicrometer or respirable fraction of the aerosol are approximately one-half of the DPM concentration.

Appendix D: References to Relevant Regulations

MSHA - Title 30, Code of Federal Regulations

Underground coal, diesel-powered equipment regulations - published in the Federal Register on October 25, 1996, Vol. 61, Number 208, pp. 55412-55534. The toolbox makes reference to the following requirements:

- approved engines required	75.1907
approval criteria	Parts 7 and 36, revised
- low sulfur fuel	75.1901(a)
- fuel additives	75.1901(c)
- maintenance of air filters	75.1914(d)
- weekly CO testing of tailpipe emissions	75.1914(g)
- compliance with manufacturer specs	75.1909(a)(1), 75.1914(f)(1)
- maintenance personnel qualifications	75.1915
- idling restrictions	75.1916(d)
- visual exam by equipment operator	75.1914(e)

Limitations applicable to certain diesel exhaust gases

- underground coal	75.321, 75.322
- surface coal	71.700
- underground metal/nonmetal	57.5001
- surface metal/nonmetal	56.5001

EPA standards for new diesel engines - Title 40, Code of Federal Regulations

- 1988 "on-highway" engine standards	40 CFR 86.088-11
- 1996 "nonroad" engine standards	40 CFR 89.112-96

Pennsylvania state standards for use of diesel-powered equipment in deep coal mines

Pennsylvania Act 182 of 1996, December 19, 1996. This Act adds a new article to the Bituminous Coal Mine Act, "Article II-A, Diesel-Powered Equipment." It takes effect on February 17, 1997. For information, contact the Bureau of Deep Mine Safety, 412-439-7469, or fax at 412-439-7324.

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